# 2.—THE GEOLOGY AND PHYSIOGRAPHY OF THE LAWNSWOOD AREA

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Read: 12th March, 1946.

CONTENTS.



## 1. INTRODUCTION.

Lawnswood is situated on the Clackline-Miling railway, three miles north of Clackline and approximately 50 miles in an east-north-east direction from Perth (see locality plan on Plate I.). The Lawnswood Area, which occupies about 10 square miles with the southern boundary less than one mile north of Clackline, is largely composed of early Pre-Cambrian rocks of the Jimperding Series (6, p. 167). This series is composed of pelitic and psammitic metasediments with intercalated layers of acid and basic igneous rocks all of which have suffered sillimanite zone regional metamorphism (26, p. 11; 23, p. 84; 9, p. 168). It extends from York (15 miles south of Clackline) to at least as far north as the Irwin River District (23, p. 84). Forman (12, p. XXV) regards this series as equivalent in age to the Whitestone and Mosquito Creek Series, which, as indicated by recent work at Southern Cross (10, p. 13), are younger than the Older Greenstones of the Kalgoorlie Series (considered to be the oldest group of rocks in Western Australia (24).

The other rocks of more limited distribution are Late Archaeozoic Younger Granite (12, p. XXV), Late Proterozoic or Lower Cambrian quartz dolerite dykes (24) and a superficial deposit of Tertiary laterite. This

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laterite, unlike most of the laterite of Australia which is horizontal (31, p. 32), is formed on a surface sloping at 4° to 8° away from the resistant metasedimentary ridges.

Two parties of senior students of the University of Western Australia carried out the field work, under the guidance of Dr. R. T. Prider, during the first vacation of 1939 and 1945. Chain and compass traverses tied to a framework of Lands and Survey Department subdivisions were employed in the mapping.

## II. PHYSIOGRAPHY.

The Great Plateau of Western Australia (15, p. 3) is generally mature, especially in the inland part of the plateau. There are, however, occasional laterite-capped mesas and buttes, the summits of which mark the level of a former peneplain, and rare monadnocks rising above the general plateau level (8, p. 11), which become more numerous towards the edge of the elevated peneplain producing an immature topography.

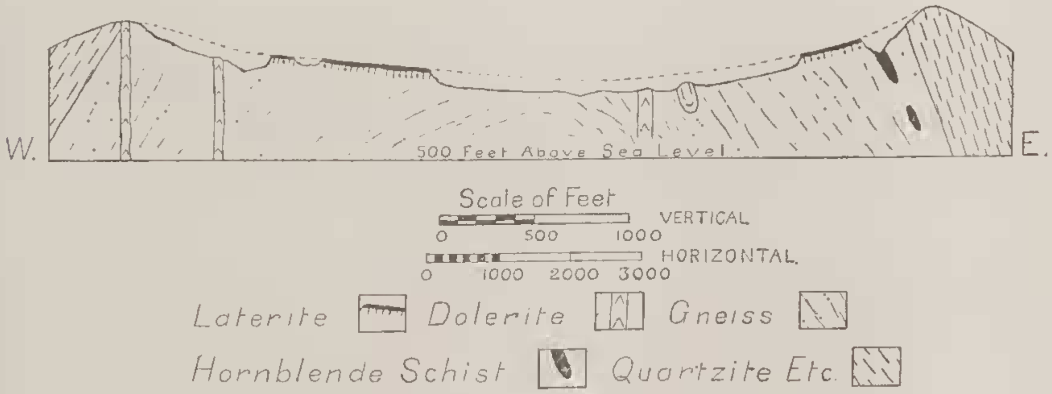
In the Lawnswood Area differential erosion and weathering, both in the present and past cycle of erosion, have been responsible for the main topographic features. As the quartzites are resistant to both weathering and erosion they form two monadnocks elongated parallel to the regional strike. The broad, mature valley running through the centre of the area corresponds to the less resistant granitic gneiss and possibly was formed by an ancient river which flowed in a south-east direction before it was captured by more vigorous west-flowing streams (14, pp. 155-156). Dolerite dykes are intermediate in resistance forming valleys in the quartzites and low ridges in the granitic gneiss (text fig. 1).

Text Fig. 1.

Three dolerite dykes in the upper granite gneiss, 20 chains south of Clackline. The dolerite dykes, being more resistant to erosion than the gneiss, form ridges. Note the parallelism of the dykes.

Differential erosion has been greatly aided by deep and long continued weathering which took place towards the end of the previous cycle of erosion. Granite and basic rocks alike were reduced to a whitish clay down to the base of the kaolinised zone, 50 to 100 feet below the laterite which was forming at that time. This extreme weathering is very unusual in Western Australia and is possibly due to moderate to heavy rainfall during the time of laterite formation forming unusually acid ground waters which altered all the rocks, with the exception of quartzite, into the residual clay deposit.

In the present cycle of erosion, differential erosion of these deeply weathered rocks has produced a dissected peneplain with laterite-capped mesas and buttes, overlying soft kaolinised rock, rising steeply above the unweathered rock to a height of 50 to 100 feet. The laterite mesas and buttes invariably slope at 4° to 8° towards the centre of the valley (see text fig. 2) and small streams consequent on this slope, which flow into a larger stream in the centre of the mature valley, have, in most places stripped off the kaolinised rock leaving the unweathered rock exposed. Very immature subsequent streams are dissecting narrow gorges in the soft hornblende and mica-schist bands in between the quartzite ridges.




Text Fig. 2.

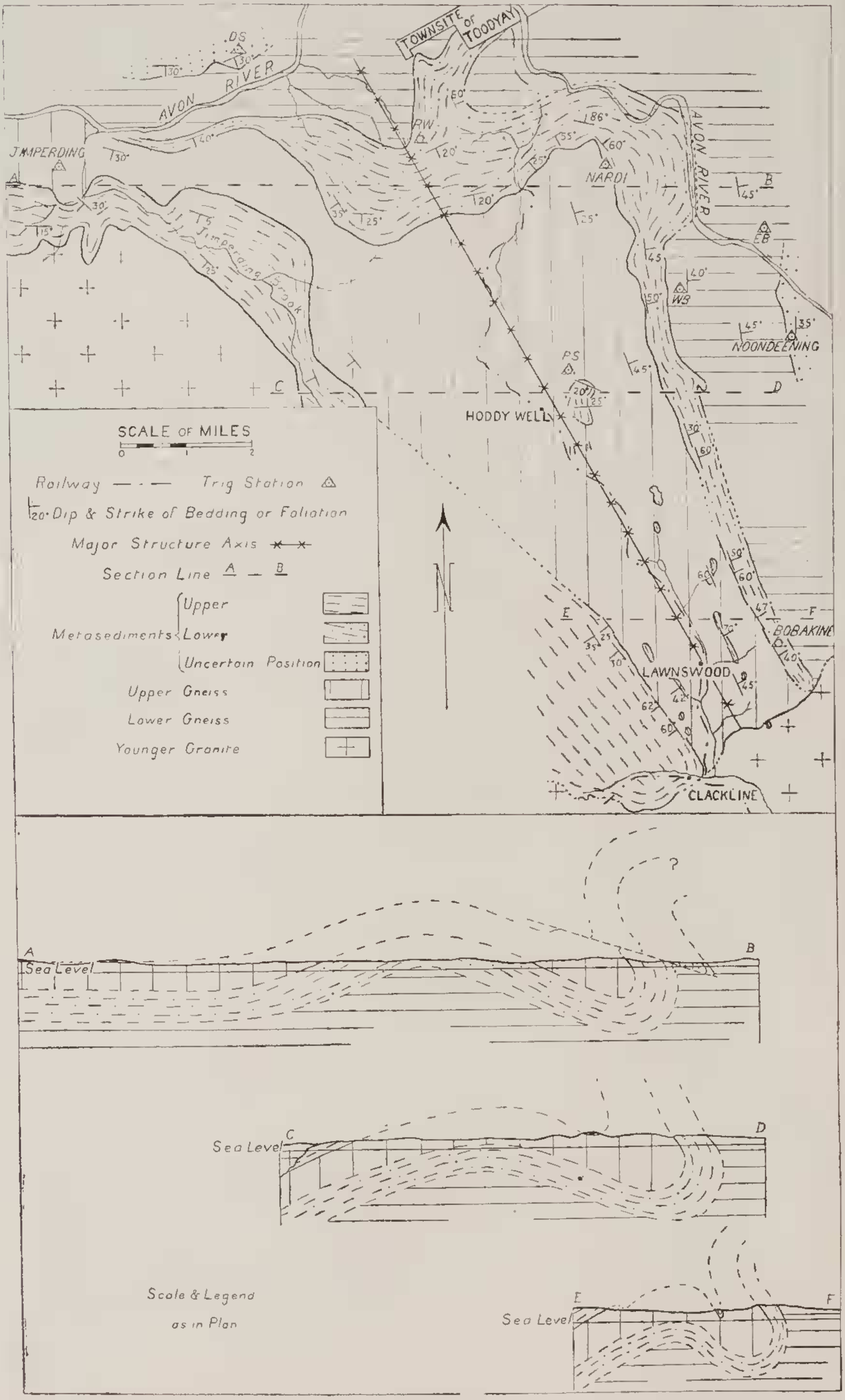
Cross section of the Lawnswood Area along a line bearing 73° at 23 chains north of Lawnswood siding, showing the laterite capped mesas which slope down towards the central valley. The old profile upon which the laterite was formed, is shown by broken lines.

## III. GEOLOGY.

### A. OCCURRENCE OF THE ROCKS.

#### 1. Metasediments and Hornblende Schists.

There are two broad bands of metasediments in the area both with the characteristic north-north-west strike. The western band which dips west at 25° to 35° in the northern part, and west at 50° to 65° in the southern part of the area, is correlated with the upper metasediment of the Toodyay Area (23, p. 88) because it is on the same line of strike (see text fig. 3) and petrologically the quartzites are identical, both containing idioblastic pale-green chrome-muscovite oriented parallel to the bedding and poikiloblastically included in the quartz grains. The eastern metasediments, which have been connected in the field to the lower quartzites of the Toodyay Area (see text fig. 3), have dips varying from 40° to 50° to the east.




Text Fig. 3.

Geological sketch plan and sections to illustrate the structure of the country between Toodyay and Clackline. Data regarding the northern half of this area after Prider (23, p. 86).

A narrow strip of metasediments (mica schist and quartzite) outcrops in the upper granite gneiss, at a distance varying from five to 12 chains from the upper quartzite. Owing to the very highly weathered nature of its component rocks it is not certain whether this band is continuous, whether it is a series of elongated lenticular xenoliths of the Jimperding Series, or whether it is an infold of the upper metasediments in the gneiss. Another narrow and discontinuous band, situated approximately 40 chains east of Nunamullen Brook, dips 70° to the east in the south, 60° to the west about a mile and a half north of Lawnswood, while in the vicinity of P.S. Trig station there is an anomalous western strike and a low dip to the south.

As the sediments have been very highly metamorphosed causing complete recrystallisation, original features, such as graded bedding and ripple marks, have been almost completely obliterated. Prider (23, p. 87), mentions that, in the Toodyay Area there are some obscure current bedding structures but no certain interpretation of these was possible. Drag folding was not observed in this area, but Prider (23. p. 87) has found drag folds in the lower quartzites of the Toodyay Area, approximately one mile south of W.B. Trig station, which indicate overturning in that locality. Minor cross folds are indicated by the variable pitch of well developed *b*- lineations in the quartzites.

### 2. Granitic Gneiss.

A thick, concordant, granitic gneiss body occupies most of the central portion of the Area corresponding with a mature valley about three miles wide (see Plate 1). This is correlated with the Upper Gneiss of the Toodyay Area. In the north-east corner of the Area, a second concordant granitic gneiss occurs, which corresponds to the Lower Gneiss of Toodyay.

Although ptygmatic folding is occasionally developed in the gneiss, as is well seen in the outcrops in the bed of Spencer's Brook at Clackline, generally the platy parallelism of the gneiss conforms closely in dip and strike with the associated metasediments. No work was done on linear parallelism of the gneiss.

### 3. Intrusive Granite.

Granite invades the Jimperding Series in the south-east corner of the Area and continues immediately south and west of Clackline. Probably the boundary of this Younger Granite and the Jimperding Series turns north within a mile west of Clackline and thence runs north to the south-west corner of the Toodyay Area (see text fig. 3).

The intrusive granite appears massive in the field except near the contact with the metasediments south and west of Clackline, where the gneiss-like banding of the rock is due possibly to platy flow structures developing near the contact with the country rocks

There are two varieties of granite, a porphyritic and an equigranular. The porphyritic is confined to the south-east part of the Area, and passes in a distance of a chain or two into the equigranular variety. The equigranular granite occupies the south-central portion of the Area and extends at least a mile west of Clackline. The porphyritic granite passes into the granitic gneiss very abruptly, but the transition from equigranular granite into granitic gneiss is very gradual.

### 4. Quartz Dolerite.

Quartz dolerite dykes, from half to two chains wide, are intrusive into all the above rocks. They have a general north-north-west trend and are most numerous in the centre of the Area. In some places there are closely spaced fractures resembling fracture cleavage in the dykes giving them a platy structure. Slight shearing of their edges indicates movement subsequent to intrusion.

### 5. Laterite.

Laterite-capped mesas and buttes are more common near the metasedimentary ridges and slope away from them at 4° to 8°. This sloping laterite is attributed to its formation on a gently inclined surface in the end stages of the previous cycle of erosion rather than to warping in late Kainozoic times, as in the case of an occurrence of dipping laterite in South Australia (31, pp. 32-33).

## B. STRUCTURAL INTERPRETATION OF THE JIMPERDING SERIES.

Text fig. 3 is a simplified diagram of the broader geological and structural features of the Toodyay and Lawnswood Areas. The northern part of the map, the two sections A-B and C-D and the interpretation of the structure are taken from Prider's paper on the Toodyay Area (23, p. 87).

Whereas from the Lawnswood Area to the southern part of the Toodyay Area the strike is north-north-west, in the north of the Toodyay Area the strike is west and the dip is to the south at a fairly low angle. Again the quartzite near P.S. Trig has a westerly strike and a low dip to the south. This unusual westerly strike, the drag fold evidence of inversion of the lower metasediments and the discontinuous quartzite band running from near P.S. Trig to the intrusive granite at the south-east of the Lawnswood Area, can be explained if we imagine the Toodyay and Lawnswood Areas to be in the main a major anticline pitching to the south-south-east, having a recumbent syncline with an axial plane dipping to the east on the eastern limb of this major anticline.

The discontinuous quartzite band from near P.S. Trig is considered to be an infolded recumbent syncline of the Upper Quartzites regardless of its petrological resemblance to the lower quartzites. Dr. Prider predicted the presence of this infolded band of upper metasediments at P.S. Trig, as a result of his structural interpretation of the Toodyay Area and he suggests that the discontinuous nature of this band is due to the presence of minor cross folds. The cross folds superimposed on the major north-west trending structure have produced a series of minor transverse synclines and anticlines. Erosion has cut down so far that only the transverse synclines remain as lenticular outcrops while the transverse anticlines have been removed.

It is seen (Table 1.) that, while the lowest portion of the Toodyay sequence is not represented in the Lawnswood Area, there is a considerably greater thickness of upper metasediments in the west of the area which probably correspond to the metasediments in the south-east of the Malkup Area (9, Table 1. p. 146). Probably of some importance in regard to the origin of the hornblende schists is the change of "Horizon 6" from sillimanite schist in the Toodyay Area to hornblende schist in the Lawnswood Area.

TABLE 1.

COMPARISON OF STRATIGRAPHICAL SUCCESSION AND THICKNESS OF THE JIMPERDING SERIES IN THE LAWNSWOOD AND TOODYAY AREAS.

| | Lawnswood Area. | | Toodyay Area. | |
|---|---|---|---|---|
| No. | Horizon. | Thickness | Horizon. | Thickness. |
| | *Lower metasediments and hornblende schists.* | | *Lower metasediments and hornblende schists.* | |
| 1 | Not represented | | Quartzite | unknown |
| 2 | Not represented | | Hornblende schist | 35ft. |
| 3 | Not represented | | Quartzite | 650ft. |
| 4 | Lower granitic gneiss | unknown | Lower granitic gneiss | 5,400ft. |
| 5 | Quartzite | 300ft. | Quartzite | 375ft. |
| 6 | Hornblende schist | 50ft. | Sillimanite schist | 100ft. |
| 7 | Quartzite | 150ft. | Quartzite | 570ft. |
| 8 | Hornblende schist | 70ft. | Hornblende schist | 40ft. |
| 9 | Quartzite | 180ft. | Quartzite | 110ft. |
| | *Upper metasediments.* | | *Upper metasediments.* | |
| 10 | Upper granitic gneiss | approx. 2,000ft. | Upper granitic gneiss | 1,900ft. |
| 11 | Quartzite with some subordinate quartzose mica schists | 250-600ft. | Quartzite | 500ft. |
| 12 | Hornblende schist | 180ft. | Indication of hornblende schist | |
| 13 | Quartzite | 60-200ft. | Not represented | |
| 14 | Mica schist and quartzite | 1,850ft. | Andalusite—muscovite schist | 250ft. |
| 15 | Quartzite and mica schist | 5 000ft.+? (Thickness may be due to incompetent folding) | Not represented | |
| 16 | Metajaspilites and banded iron-ore | 5 000ft.+? (Thickness may be due to incompetent folding) | Not represented | |

## IV. PETROLOGY.

The rocks are divided into two groups:—

A. The Jimperding Series.

B. The younger igneous intrusives.

### A. THE JIMPERDING SERIES.

#### 1. Metasediments.

(a) *Quartzites.*

These are coarse-grained almost pure quartz rocks with well defined bedding on which corrugations or *b*- lineations (19, p. 591) are developed. The Lawnswood quartzites are identical with those described by Prider at Toodyay (23, pp. 88-94).

(i) The Upper Quartzites are characterised by the presence of small ($< 0.1$ mm.) pale green chrome-muscovite idioblasts enclosed in the quartz grains and oriented parallel to the bedding. Felspar is not found in the main band of upper quartzites in the west of the Lawnswood Area but is common in the infolded quartzite which is correlated with the upper quartzites on structural grounds.

(ii) The Lower Quartzites are identical with those of the Toodyay Area and have been connected in the field. The chrome-muscovite grains are larger than those in the Upper Quartzite being 0.3 to 0.5 mm. in diameter and lie between the grains of the quartz mosaic, while there are poikiloblastic inclusions of rutile, magnetite, sillimanite (?), felspar, and zircon in the quartz grains.

(iii) The Infolded Quartzites lithologically resemble the Lower Quartzites, being a felspathic variety free from oriented, poikiloblastic inclusions of idioblastic chrome-muscovite in the quartz grains. The felspar is slightly kaolinised microcline with frequent microperthite which generally occurs in xenoblasts up to one mm. in diameter in the quartz mosaic and may form five to six per cent. of the rock. The inclusions in the quartz grains are zircon, red-brown biotite and a green pyroxene, forming two to three per cent. of one rock (22742)*.

*Origin of the quartzites.*—The quartzites appear to have been derived from remarkably pure quartz sands which have recrystallized in the sillimanite zone resulting in the obliteration of the clastic structure (23, pp. 92 and 94).

(b) *Mica Schist.*

The mica schists occur in the western metasedimentary band and are light yellow-brown to grey brown, generally highly schistose, medium-grained, micaceous rocks which are frequently contorted. The characteristic features of these rocks are the constant presence of bands and lenses of sillimanite in very fine aggregates of acicular crystals which are frequently altered to sericite (26, p. 13) and the marked schistosity—the quartz grains having an index of elongation of four to five.

(i) The Muscovite-quartz-sillimanite schist (22569) has the following minerals visible in hand specimen:—golden plates of muscovite two to three mm. in length; colourless, strongly elongated quartz grains three to five mm. long; and bands up to two cm. wide and more than 10 cm. long containing an aggregate of fine white acicular sillimanite and sericite. There are rare inclusions of sericite and minute sillimanite prisms in the quartz and very corroded biotite is sometimes observed. The complete absence of undulose extinction in the elongated quartz grains indicates that complete recrystallisation took place during metamorphism.

The approximate mineralogical composition is muscovite 40 per cent. quartz 30 per cent. sericite 30 per cent. with biotite, sillimanite and iron ores accessory.

The sericite-sillimanite bands become most common in the south of the area in the vicinity of the Clackline fire-clay deposits, which are highly kaolinised sillimanite-mica schists composed largely of white kaolin with up to 10 per cent. of lenticular bands of very acicular sillimanite (26, p. 12). Quartz and kaolinised muscovite are visible in hand specimens. This sillimanite clay lies close to the Younger Granite and several pegmatite veins, genetically related to this granite, occur in the west of the deposit.

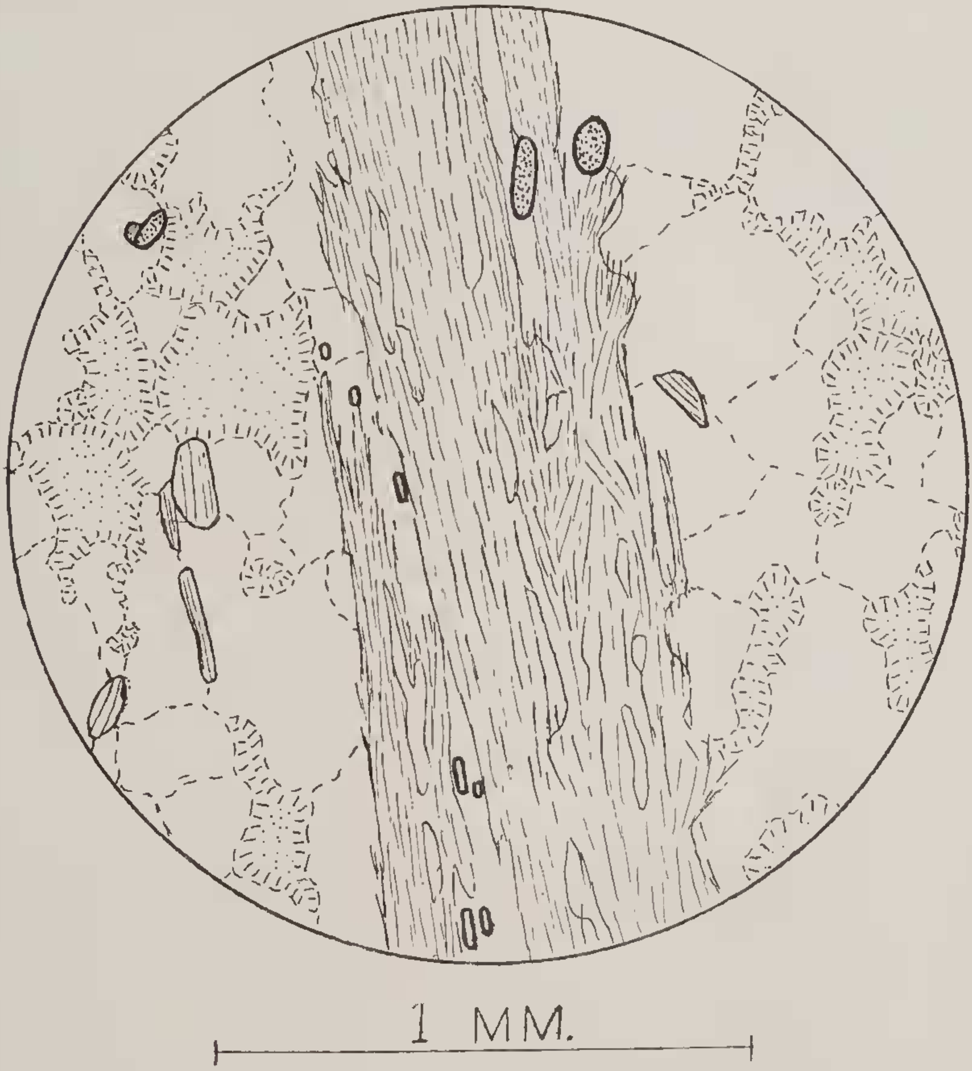
Mr. H. Bowley "picked up a loose crystal of kyanite a little to the north of the brickpit" (26, p. 11), but no kyanite has been found in the present investigation.

A lateritised form of the muscovite-quartz sillimanite schist (22568. 22569, 22570) occurs in a band in the upper granitic gneiss about 10 chains

*Numbers refer to the catalogue of the collection of the Department of Geology of the University of W.A.

east of the upper metasediments. This is petrologically indentical with unlateritised specimens (22539) from the base of the upper metasediments and is correlated with horizon 11 (Table 1.).

(ii) The Biotite-cordierite-quartz-sericite-sillimanite schist (19190) is frequently darker in colour and more gneissic than group (i). The biotite occurs in markedly elongated, strongly pleochroic plates — Y and Z = brown, X = very light brown to colourless, absorption $X < Y = Z$, c $X = 0°$, (-)2V very small. Pleochroic haloes around zircon grains are frequent. The quartz is very elongated and contains gas-liquid inclusions and minute inclusions of sericite, rutile, rounded zircon and rare sillimanite. Cordierite was observed in an irregular intergrowth with quartz in one slide (19953) but equidimensional sericite aggregates are possibly pinite pseudomorphic after cordierite. The sericite aggregates are evidently derived some from bands of sillimanite and some from an equidimensional mineral —probably cordierite or even felspar (see text fig. 4). The sillimanite is




Text Fig. 4.

Biotite-corderite-quartz-sericite-sillimanite schist (19190), showing a band of sericite pseudomorphic after sillimanite (small prisms with high relief) and equidimensional grains consisting of sericite after corderite (or felspar). Four rounded grains of rutile are seen in this field.

the variety fibrolite occurring in very fine prisms associated with elongated magnetite grains. It appears to be developing at the expense of biotite (23, p. 98). Muscovite, iron ores, zircon, sillimanite, and felspars, the latter occurring only in specimens from near the intrusive granite, are accessory minerals.

The average composition is quartz 40 per cent., biotite 15 per cent., cordierite and pinite 15 per cent., sericite 15 to 20 per cent., fibrolite is sometimes as high as 10 per cent.

(iii) Garnet schist.—A highly weathered whitish to brownish schist with numerous equidimensional, dark brown limonitic grains pseudomorphic after garnet (the original crystalline form being retained) has been noted only in the fire-clay quarry at Clackline. The rock has a maculose texture with about 40 per cent. of limonite pseudomorphs after garnet three to five mm. in diameter, the remainder of the rock being fine-grained quartz and mica.

*Origin of the mica schists.*—These mica schists are thought to be the result of extreme regional metamorphism of sandy argillaceous sediments or possibly glauconitic shales (26, p. 13).

Sillimanite-quartz-cordierite-biotite schists were probably formed at this stage of high regional metamorphism, with a tendency of the biotite to change to fibrolite and magnetite. Probably the original composition of the sediment determined whether the schist formed therefrom was high in sillimanite, mica, or garnet.

The sillimanite clay quarried at Clackline is thought to be a highly kaolinised variety of sillimanite-rich mica schist from the kaolinised zone below the laterite, i.e., the result of weathering, and not the result of hydrothermal metasomatism at the time of the intrusion of the Younger Granite, as are the sillimanitic clay deposits at Williamstown, South Australia (1, p. 10).

Considerable retrograde metamorphism probably took place as a result of the intrusion of the Younger Granite. "Hot alkaline potash solutions" (26, p. 13) metasomatised the sillimanite and cordierite producing sericite after sillimanite and pinite after cordierite and some of the biotite was altered to muscovite.

(c) *Metajaspilites.*

(i) Banded quartz-magnetite-garnet-amphibole rocks have been described by Miles (17, pp. 325-328). Megascopically they are heavy, dark green, medium to coarse-grained, granular, coarsely banded rocks. The banding is considered to be a relict structure of the original bedding. In (19956) there are three types of bands: (1) Quartz-rich with subordinate pale green amphibole (grain size of both two to three mm.); (2) a layer in which pale green amphibole predominates and which has subordinate dark amphibole and garnet and rare magnetite; (3) a layer of red garnet (1 mm. diam.), dark amphibole ( two to three mm. diam.) and magnetite ( half to one mm. diam.) with subordinate pale green amphibole.

The rock has a coarse granoblastic structure. The quartz forms a coarse mosaic and has gas-liquid inclusions and sometimes slight undulose extinction. Xenoblastic inclusions of amphibole sometimes occur in the quartz.

The amphiboles are of two varieties, both with a high relief, containing pleochroic haloes around zircon grains and tending to be idioblastic in form (17, pp. 327 to 328). One variety is a pale green amphibole with weak pleochroism, X = colourless, Y = b = pale yellow green to brown, Z = pale green-blue; absorption X $<$ Y $<=$ Z; Z $\wedge$ c = 13°; (-) 2 V near 90°. Polysynthetic twinning is common on 100. The mineral is a grunerite with a composition near cummingtonite probably containing over 75 per cent $FeSiO_3$ (17, p. 327). The other variety is a dark amphibole with very strong pleochroism X = light green, Y = dark olive green, Z = intense blue-green. Absorption is strong and masks the interference colours, Z slightly $>$ Y $>$ X, Z $\wedge$ c = 22°, Y = b, optical character biaxial -ve with large 2V (about 80°), twinning not seen. The mineral is probably an actinolitic hornblende. The garnet xenoblasts have an irregular form and a poikiloblastic character. They contain numerous inclusions of a highly birefringent mineral forming up to 60 per cent. of their volume. This garnet is a pink, probably iron-rich variety. Magnetite forms very irregular patches. The crystalloblastic order is: amphiboles, garnet, quartz and magnetite. Average composition—quartz 40 per cent., grunerite 30 per cent., dark green amphibole 15 per cent., garnet 15 per cent., magnetite accessory.

(ii) Banded quartz-iron ore rocks (19954) are bluish grey, strongly banded, fine to medium-grained, with a granular texture, and are reddish brown where weathered.

The bands are quartz, four cm. wide (grain-size about two mm.), quartz and iron ore, one cm. wide (grain-size 0.25 - 0.5 mm.), and narrow iron ore bands up to one mm. wide (grain-size 0.25 mm.). Bands of amphibole occur rarely.

A granoblastic structure is seen in the quartz and quartz-iron ore bands. The quartz has an irregular mosaic structure and is practically free from inclusions except next to the iron ore where it is crowded with fine, colourless, needle-shaped crystals. These are indeterminable but are perhaps incipient grunerite resulting from reaction between quartz and the iron ores. The iron ore is almost entirely hematite but a minor amount of magnetite is present and quite a number of octahedral crystals were observed, some of which may be hematite pseudomorphic after magnetite.

(iii) Lateritised banded quartz-iron ore rock (19961) is a brownish coloured rock which outcrops in the south-west corner of the area. It consists of alternating bands of quartzite and limonite, from one cm. to three cm. or more in width. The quartz (grain-size two to three mm.) has a mosaic structure. Sometimes the rock is almost pure, very fine-grained limonite which is dark brown and has a metallic lustre, other specimens are composed of dull limonite and strikingly resemble the rocks of group (ii).

Drag-folded and very contorted quartzites, called "banded quartzite" by Mr. R. A. Hobson of the Geological Survey of Western Australia who mapped the area in 1941, are very commonly associated with the banded iron ores. The data concerning the banded quartzite and banded iron ore in the south-west corner of the geological map of this area are taken from Hobson's map.

*Origin of the metajaspilites.*—Extreme metamorphism in the sillimanite zone of iron-rich siliceous sediments has produced these banded iron and silica-rich rocks. Probably the original rocks were finely bedded quartz sands and magnetite sands, similar to those of Yampi Sound (5, pp. 67-75), with some bands of impure iron-rich sediments containing greenalite or siderite (17, p. 369).

As banded hematite-quartz rocks with little or no amphibole (ii) occur, it appears that pure iron ores and quartz do not react to any extent, so it is considered that group (ii) is derived from finely laminated quartz-magnetite sediments, while group (i), in which iron-rich amphiboles and garnet are present, is the result of intense metamorphism of banded quartz and impure iron-rich sediments (greenalite or ferrous carbonate).

Group (iii) is considered to be the result of lateritisation of the metajaspilites especially the very iron-rich forms. This is a case of extreme retrograde metamorphism (katamorphism) as a result of weathering of high grade metamorphic rocks. The original bedded structure is in most cases clearly visible, the iron-rich minerals apparently have been metasomatically replaced by limonite so the rock may be considered to be a lateritoid (a term proposed by Fermor (11, pp. 381-3) for rocks similar to laterite but formed by metasomatism).

## 2. Meta-igneous Rocks.

(a) *Hornblende schist and its variants.*

These are fine to medium-grained, uniform-textured, schistose rocks dark greenish grey in colour and identical with those of the Toodyay Area (23, p. 104-107). A granoblastic microstructure and the absence of any distinct crystalloblastic order is characteristic of the group.

(i) Quartz-plagioclase amphibolite (22733) is the most common type as it is in the Toodyay Area (23, p. 104-105). The optical properties of the hornblende at Lawnswood are X = yellow, b = Y = olive green, Z = blue-green, absorption X > Z > Y, (-) 2V large, c $\wedge$ Z = 20°, $\beta$ = 1.679. Its approximate composition is hornblende 65 per cent., oligoclase ($Ab_8$ $An_2$) 25 per cent., quartz five per cent., accessories (microcline, radio-active titanite and green diopside) five per cent.

(ii) Quartz-plagioclase-pyroxene granulite (22732) is a variant of the plagioclase amphibolite. It is a granular type in which green diopside is greatly developed while hornblende is rare or absent. The diopside is a bright green very feebly pleochroic variety, Z and X appearing to be green and b = Y = yellow green, optically positive, c $\wedge$ Z = 40° with simple twinning developed. The approximate composition of this is diopside 50 per cent., oligoclase 45 per cent., quartz four per cent., titanite one per cent.

(iii) Quartz-zoisite-hornblende schist (22583)—The hornblende schist layer intercalated in the western metasediments differs from those described above in the predominance of quartz and the absence of felspar. The presence of an aggregate of zoisite and sericite is probably the result of retrograde metamorphism (felspar $\Rightarrow$ sericite + zoisite). Accessories are apatite, iron ores, purple zircon, and rutile. Titanite is absent. The approximate composition is quartz 55 per cent., hornblende 30 per cent., zoisite and sericite 15 per cent.

*Origin of the hornblende schists.*—Types (i) and (ii) are thought to be the result of extreme regional metamorphism of basic igneous flows or sills, as, according to Wiseman (30, p.394), hornblende with a refractive index of $\beta = 1.679$ is indicative of an epidiorite formed in the sillimanite zone of metamorphism. Prider (23, p. 107) concluded, from the high refractive index of the hornblende, the occurrence of the rocks in beds intercalated with the metasediments and their chemical composition, that similar hornblende schists in the Toodyay Area are highly metamorphosed basic igneous rocks.

Previously when dealing with the correlation of the Toodyay and Lawnswood Areas it was pointed out that Horizon 6 (see Table 1.) is a hornblende schist in the Lawnswood Area and a sillimanite schist in the Toodyay Area. The presence of hornblende schist in the same horizon as sillimanite schist suggests that this hornblende schist was a basic (dolerite) sill that was injected in some places into a softer argillaceous stratum between two arenaceous bands prior to regional folding.

The quartz-rich hornblende schist (iii) is thought to be the result of extreme metamorphism of a basic sediment (greywacke) or basic tuff.

(b) *Cordierite-anthophyllite rock.*

About 50 chains west of Clackline an outcrop of a light greyish-green, medium to coarse-grained, uniform-textured cordierite-anthophyllite rock occurs. It has been described by Simpson (27, p. 115). It outcrops at the contact between the Jimperding Series metasediments, which are peltic in this exposure, and a rock which is thought to be the Younger Granite although it is gneissic.

The minerals are greyish-green cordierite, devoid of cleavage and up to three mm. in length, and grey prisms of anthophyllite up to two mm. in length. The microstructure is granoblastic gneissic. Cordierite occurs in colourless xenoblasts frequently altered along irregular cracks to pinite, and the anthophyllite is generally idioblastic. Red-brown biotite, rutile, and chromite are accessory. The approximate composition is cordierite (and pinite) 55 per cent., anthophyllite 45 per cent.

Simpson (27, p. 116) suggests that this rock originated by the "absorption of some slate or similar aluminous rock" into a basic hypersthene-rich rock. Similar cordierite-anthophyllite rocks occur as xenoliths in the granitic gneiss of the Toodyay Area, and these have been shown to be genetically related to an ultrabasic spinel-olivine-hypersthene rock. Prider concluded that a "hypersthenite magma which had been contaminated by assimilation of aluminous material" had been altered to cordierite anthophyllite rock "by the simple addition of silica (probably from the granite)" (21, p. 381).

The presence of mica schist adjacent to the cordierite-anthophyllite rock in the Clackline occurrence suggests that a hypersthenite invaded a pelitic band of the metasediments and assimilated aluminous material, as Simpson suggests. The cordierite was formed either during the highest stages of regional metamorphism or more probably as a result of the contact metamorphism (with silica addition) by the Younger Granite.

### 3. Granitic Gneiss and associated xenoliths.

The granitic gneiss is in two thick sills continuous with the Toodyay Area. The lower granitic gneiss outcrops in the north-east of the Lawnswood Area while the upper granitic gneiss covers its centre and has been studied in some detail.

(a) *Upper granitic gneiss.*

This gneiss is almost identical with the one described by Prider at Toodyay (23, pp. 107-111) except for the absence of augen structure.

There appear to be two main types:—(i) Granitic Gneiss A (chloritic) which is a medium- to coarse-grained, greyish gneiss, with widely spaced microcline phenocrysts (two cm. diam.) and is characterised by the presence of chlorite and epidote; (ii) Granitic Gneiss B (biotitic), which occupies the edge of the sill near the metasediments, being characterised by a finer grain, a more strongly developed gneissic structure and the presence of biotite.

(i) Granitic Gneiss A (chloritic) (22479)—The type rock has a coarsely gneissic structure sometimes with slight cataclasis and the following minerals:—slightly saussuritised oligoclase, clear microcline, quartz, chlorite, epidote (often in veinlets), and accessory apatite, magnetite, and zircon. The chlorite occurs in well developed plates frequently with purple zircon inclusions surrounded by strong pleochroic haloes. It is thought to be pseudomorphic after biotite because of its form and the purple zircon inclusions which are common to both. Its optical properties are:—pleochroism X = very pale yellow-green, Y and Z = green, absorption $X > Y = Z$, birefringence very low, anomalous blue colours frequent, elongation positive, optically negative, $\beta = 1.625$. These data indicate the variety as aphrosiderite which has a composition similar to biotite.

Approximate composition is oligoclase 35 per cent., quartz 30 per cent., microcline 25 per cent., chlorite five per cent., epidote five per cent.

(ii) Granitic Gneiss B (biotitic) (22574) is characterised by biotite in very elongated plates rather than chlorite and epidote pseudomorphic after biotite as in (i). The biotite plates are crowded with sagenitic rutile inclusions and have strong pleochroism X = yellow, Y = dark brownish green, Z = very dark brown, absorption $X < Y < Z$. Microcline phenocrysts are absent but some larger grains (two to three mm.) slightly kaolinised and with myrmekite frequently developed in associated oligoclase, probably represent early-formed microcline, while smaller (0.5 mm.) clear grains, strongly cross-hatched and containing microperthite are probably a later generation. The quartz generally occurs in rounded grains poikiloblastically enclosed in all the other minerals.

The approximate composition is microcline 35 per cent., quartz 35 per cent., oligoclase 15 per cent., biotite 15 per cent.

(b) *Xenoliths in the granitic gneiss.*

These are of amphibolites, except for one of sillimanite-mica schist and some of chlorite-epidote rock. Generally they are large, up to two or three chains in major diameter, and irregular, and are elongated parallel to the regional strike.

(i) The amphibolites are dark, grey-green medium- to coarse-grained, melanocratic rocks containing hornblende, plagioclase and diopside with accessory biotite, apatite, quartz, and sphene and are almost identical mineralogically with the hornblende schists of the metasediments. There are both granulose and schistose varieties.

Granulose quartz-plagioclase amphibolites (22524) are dark grey, uniform textured rocks with a medium to coarse grain and a granoblastic microstructure. The minerals present are intensely pleochroic blue-green hornblende ($c \wedge Z = 21°$, $\beta = 1.672$), basic oligoclase (saussuritised and with normal gradational zoning occasionally developed), strongly pleochroic greenish-brown biotite, quartz, and accessory apatite, radioactive titanite, actinolite and diopside.

The approximate composition is hornblende 65 per cent., oligoclase 25 per cent., biotite five per cent., quartz three per cent., titanite two per cent.

The schistose quartz-diopside-plagioclase amphibolites (19188) differ from the above in their schistose structure and greenish-grey colour due to the presence of green diopside which sometimes forms more than 10 per cent. of the rock. The hornblende is similar to that in the granulose amphibolites ($c \wedge Z = 24°$, $\beta = 1.675$); andesine ($Ab_4 An_6$) is the plagioclase present; and the diopside is a green variety with very feeble pleochroism, (+) 2V large, $c \wedge Z = 41°$.

(ii) The quartz-plagioclase-epidote-chlorite rock (22487) is greenish-grey with a uniform texture and fine grain. Occasional veinlets of pale yellow-green epidote are seen in the rock. The minerals are a very dark green platy chlorite, average grain size 0.5 mm., veinlets and aggregates of pale yellow green epidote, equidimensional white grains of felspar 0.5 - 1.0 mm. in diameter. There is a slight banding caused by the parallelism of the chlorite plates.

A chemical analysis of 22487 (Table 2, I) shows that except for higher $SiO_2$ and $Al_2O_3$ and the proportional lowering of the other constituents the rock chemically resembles a hornblende schist xenolith (Table 2, II) in the gneiss from Toodyay (23, p. 105).

The rock is a rare type as shown by the quantitative classification (II, 4, 5), only one comparable rock, a gabbro, being listed in Washington's "Chemical Analyses of Igneous Rocks" (28, p. 419).

The composition except for the high $SiO_2$ is somewhat similar to that of quartz dolerite so that the rock might be the result of the granitization of a basic igneous rock.

The rock (22487) has a granoblastic microstructure with a tendency to be finely gneissic. The quartz is generally clear with an irregular form. Inclusions of chlorite are rare and an intergrowth of quartz and untwinned plagioclase is sometimes observed. Chlorite is green, practically isotropic with occasional grey blue anomalous interference colours and weak pleochroism from green to light yellow green. It appears to be pseudomorphic after an amphibole as it occurs in forms similar to the typical amphibole basal section and occasional bands of epidote cross the chlorite at angles of about 60° which may be replacements along the amphibole cleavages. Epidote forms irregular aggregates (average diameter 0.5 mm.) which may in part replace felspars. Some epidote was introduced at a later stage along cracks. The felspar is untwinned oligoclase which is difficult to distinguish from quartz. Accessory minerals are apatite, titanite, iron ore, and zircon.

The approximate mineralogical composition is quartz 32 per cent., chlorite 30 per cent., epidote 25 per cent., plagioclase 10 per cent., and titanite and other accessories three per cent. Another specimen of this group (22488) is almost black in colour and contains 80 per cent. chlorite.

Table 2.

| | I. % | II. % |
|---|---|---|
| $SiO_2$ | 59·23 | 50·20 |
| $Al_2O_3$ | 16·18 | 15·00 |
| $Fe_2O_3$ | 1·48 | 3·83 |
| FeO | 5·63 | 8·93 |
| MgO | 4·24 | 6·04 |
| CaO | 9·58 | 10·65 |
| $K_2O$ | 0·10 | 0·07 |
| $Na_2O$ | 0·65 | 1·90 |
| $H_2O+$ | 1·71 | 1·62 |
| $H_2O-$ | 0·20 | 0·07 |
| $TiO_2$ | 0·61 | 1·06 |
| MnO | 0·13 | 0·16 |
| $P_2O_5$ | 0·19 | 0·12 |
| BaO | Nil | ... |
| $ZrO_2$ | Nil | ... |
| S | 0·03 | ... |
| | 99·96 | 99·65 |
| Norms. | | |
| Q | 25·86 | 6·18 |
| Or | 0·56 | 0·56 |
| Ab | 5·76 | 16·24 |
| An | 40·87 | 31·97 |
| di | 4·86 | 16·41 |
| hy | 11·50 | 19·18 |
| mg | 2·09 | 5·57 |
| il | 1·22 | 2·13 |
| ap | 0·34 | 0·34 |
| py | 0·10 | ... |

C.I.P.W. classification II, 4, 5.

I. Quartz-plagioclase-epidote-chlorite rock (22487), xenolith in upper granitic gneiss, Lawnswood, W.A. (*Anal.* J. R. H. McWhae).

II. Schistose plagioclase amphibolite (1241) xenolith in upper granitic gneiss, Toodyay, W.A. (23, p. 105).

(iii) Sillimanite-mica schist (19193) is a slightly contorted, lustrous, grey schist, composed largely of platy mica, two to four mm. long, some of which is black biotite. Xenoliths of this type are of rare occurrence.

The main constituent is muscovite which has 2V approximately 40°. It contains poikiloblastic inclusions of sericite and chloritised biotite.

Biotite is highly corroded and brownish in colour where associated with sericite and its pleochroism is weak, X = light brown, Y and Z = brown. Where associated with muscovite the biotite is invariably altered to green chlorite. Sillimanite, variety fibrolite, occurs in bands of fine acicular aggregates and is largely altered to sericite. Magnetite and sillimanite are accessory. Primary minerals appear to have been muscovite, biotite, and sillimanite; secondary minerals sericite, chlorite, and magnetite.

The approximate composition is muscovite 36 per cent., sericite 30 per cent., biotite 20 per cent., chlorite seven per cent., sillimanite five per cent., magnetite two per cent.

(iv) Hybridised granitic gneiss.—There are several small occurrences of intermediate to basic rocks formed by the partial granitization of the basic xenoliths. They vary from basic hornblende pegmatites, with hornblende, quartz, and felspar grains two or three cm. in diameter, through coarsely banded diopside-plagioclase amphibolites with small scale "lit-par-lit" injections of quartz and microcline from the granite, to strongly gneissic acid to intermediate rocks injected by numerous quartz veins (22529). The latter type is light grey in colour and consists of an aggregate of fine-grained, blue-green hornblende, quartz, felspar and diopside in bands one to three mm. wide alternating with sill-like bands of quartz from one to four mm. wide. A similar gneiss has been described from Toodyay (23, pp. 122-123).

*Origin of the granitic gneiss and associated xenoliths.*—This granitic gneiss is either a concordant acid intrusion or results from the granitization of sediments. If the gneiss resulted from the granitization of an acid sediment (arkose) then such granitization would be expected to transgress the stratigraphic horizons of the metasediments and other metasediments such as mica schists should also show the effects of granitization. As this is not the case and as the granitic gneiss contains different kinds of xenoliths it is considered to have been introduced as a highly viscous magma during the period of diastrophism. Ptygmatic folding, protoclastic structures, and the absence of preferred orientation in the quartz grains of these gneisses suggests that the magma was a viscous fluid, crowded with early formed phenocrysts and xenoliths during the folding, the quartz crystallising when the tectonic activity had ceased (23, p. 109).

The magma is considered to have been introduced at a considerable depth on the basis of the following generalizations of Bucher and Balk: "large concordant acid intrusives in folded sediments are wide spread only in early pre-Cambrian terranes" (1, p. 284); and "deep levels in the earth.........and slow consolidation of the mass during continuous movement are probably amongst the factors which seem to result in thick foliated shells" (2, p. 81). The more pronounced platy parallelism of the gneiss near its contact with the metasediments is probably due to movement of the quasi-solid granitic magma against the relatively stationary metasediments.

The typical granitic gneiss A has an abundance of hydrothermal minerals—epidote, chlorite, and "saussurite"—which were probably formed during the end stages of consolidation. Pegmatite and quartz veins are frequent, some possibly derived from the Younger Granite.

Granitic gneiss B, which has no hydrothermal minerals and contains greenish brown biotite, is considered to be a less altered form of A formed in the border zone of the cooling magma by more rapid cooling and greater frictional forces.

A cataclastic form of the granitic gneiss, greenish in colour, with strained and cracked plagioclase grains, undulose extinction in the quartz and with much introduced epidote, is frequently found near epidote-filled veinlets genetically related to the much younger dolerite dykes.

The great bulk of the xenoliths are amphibolites which suggest, by their chemical and mineralogical composition (23, p. 105) that they are derived from the hornblende schists with little or no addition of material from the gneisses. The presence of quartz in these basic rocks is probably due to the conversion of pyroxenes to hornblende liberating silica (13, p. 311). The high refractive indices of the hornblende ( $\beta = 1.672$ and $\beta = 1.675$) is indicative of recrystallisation of a basic igneous rock in the sillimanite zone (30, p. 107). According to Harker (13, p. 281), at the highest grade of regional metamorphism of basic igneous rocks, in bands "richer in lime, the place of hornblende is partly or wholly taken by colourless diopside" and the felspar is commonly a medium andesine. These features were noted in the petrological examination of the amphibolites.

The hybridised granitic gneiss (iv) is considered to be the result of partial assimilation and granitization of these xenoliths by the granitic gneiss magma, and small scale lit-par-lit injection of acid material into the xenoliths from the magma.

The basic epidote chlorite xenolith (ii) is considered to be a xenolith of basic igneous rock similar to the hornblende schists xenoliths in the gneiss at Toodyay except that it has been extensively chloritized.

The sillimanite-mica schist xenolith (iii) is a fragment from the mica schists of the metasediments.

## B. THE YOUNGER IGNEOUS INTRUSIVES.

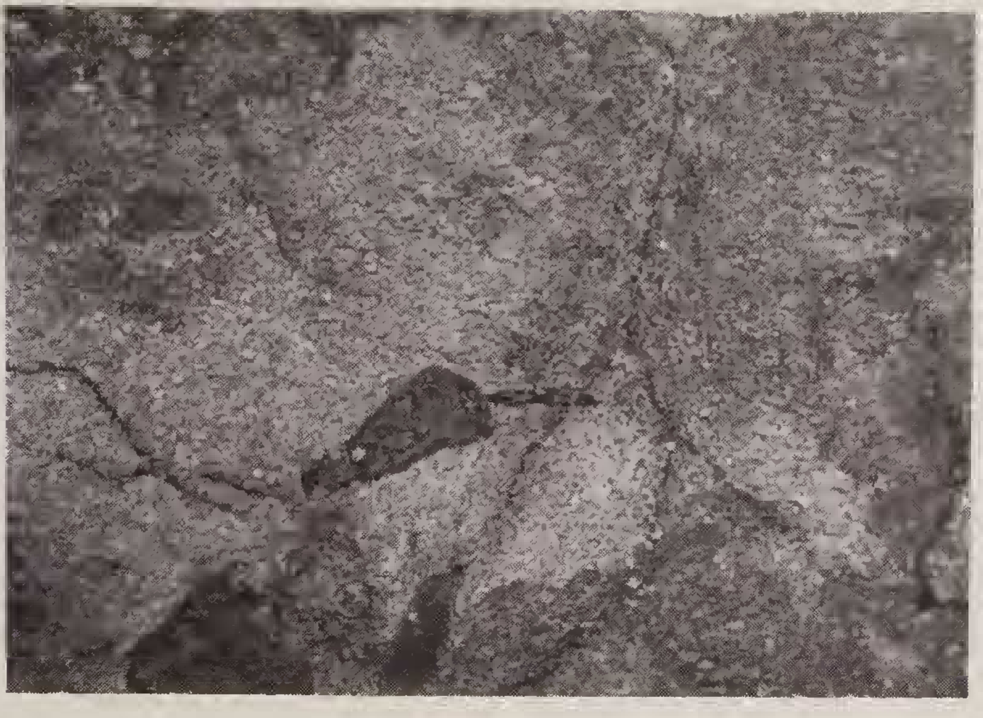
### 1. Younger Granites.

Porphyritic granite occurs in the south-east corner of the area and in a small intrusion into the granitic gneiss, about an acre in area, near the eastern metasediments. In the south-central portion of the area a uniform-grained granite takes the place of the porphyritic type. About 30 chains north of this a small dyke of gneissic granite outcrops.

(a) *Porphyritic granite and xenoliths.*

A characteristic feature of this rock wherever seen in the field, is the presence of xenoliths up to four feet in diameter of finer-grained slightly darker-coloured material (text fig. 5).

The granite itself is a coarse-grained, porphyritic rock light grey in colour with frequent small, rounded grey xenoliths up to four feet in diameter. The "phenocrysts" are euhedral microclines averaging an inch in length which are dotted with random orientation throughout the granite and also in the xenoliths (text fig. 5). The groundmass is composed of



Text Fig. 5.

Porphyritic Younger Granite with adamellite xenoliths. Note the "phenocrysts" of microcline which have developed both in the xenoliths (compare rapakivi ovoids) and in the granite itself. Note also the absence of any preferred orientation of the microcline "phenocrysts" of the granite.

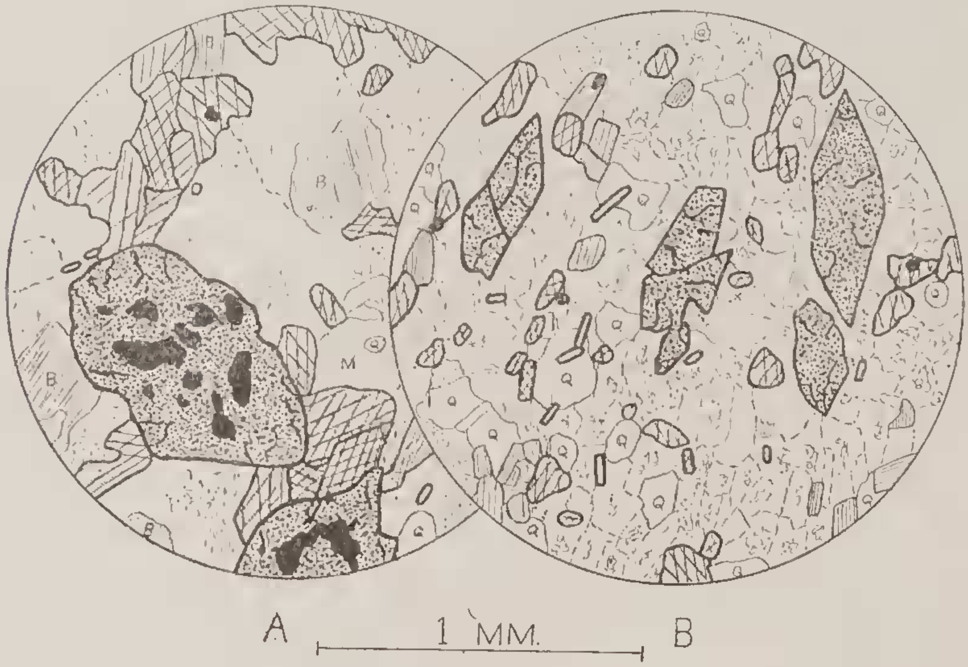
colourless glassy quartz about five mm. in diameter, pale green oligoclase, three to five mm. in diameter, pink microcline average diameter five mm. and black biotite and hornblende average grain size four mm.

The microcline "phenocrysts" are euhedral with many poikiloblastic inclusions of felspar, quartz, biotite, and hornblende. Smaller euhedral microcline grains, sometimes very slightly kaolinised, occur in the groundmass. Microperthite is frequently developed in the microcline. Oligoclase forms euhedral grains which are either extremely saussuritised, the "saussurite" being much coarser than in the granitic gneisses, or clear and slightly zoned with well developed lamellar twinning. The saussuritised oligoclase is thought to be a relic from the granitic gneiss. Coarse myrmekite structures are common. Quartz occurs in clear very irregular grains, free from inclusions, and appears to have crystallised last in interstices between earlier formed oligoclase, biotite, hornblende, and microcline. The biotite is a strongly pleochroic brown variety with subhedral form, usually occurring in aggregates with the other ferromagnesian minerals surrounding the colourless felspar and quartz grains. It has (-) 2V very small, pleochroism strong Y and Z = dark brown, X light brown, absorption $Y = Z$, $b > X$, $< c\ X = 0°$. There are pleochroic haloes around purple zircon inclusions and other inclusions of apatite and epidote. The hornblende is a strongly pleochroic type X = yellow, Y = b = dark grey green, Z = bluish green, absorption $X < Y < Z$, $c \wedge Z = 24°$, optically negative. Accessory minerals are titanite, magnetite, apatite and epidote.

Order of crystallisation:—Magnetite, titanite, apatite, hornblende, biotite, oligoclase, microcline, and quartz. The average composition is quartz 35 per cent., microcline 30 per cent., oligoclase 20 per cent., biotite 7 per cent., hornblende 5 per cent., titanite and magnetite 3 per cent.

The xenoliths in this granite are grey, coarse-textured rocks containing the same minerals as the granite but with a much higher percentage of ferromagnesians. Occasional microcline "phenocrysts" up to one inch long occur in the xenoliths (see text fig. 5). Some of the xenoliths are slightly gneissic (text fig. 6B).

The rock forming these xenoliths appears to be fairly constant in character. It has a granitic micro-structure. The minerals have the same optical properties as those in the granite, and are biotite with sagenitic rutile webbing, (grain-size up to two mm.), greenish-blue hornblende, (grain-size two to four mm.), saussuritised oligoclase with inclusions of magnetite and chlorite, (grain-size four to six mm.). Quartz and microcline are clear and very irregular in form and occur in variable quantities from two per cent. to 30 per cent. Grain-size two to five mm. except for rare microcline "phenocrysts" crowded with inclusions of all the other minerals which have an average size of 2 cm. Large (one mm.) euhedral titanite grains, probably the result of the alteration of original ilmenite, have inclusions of magnetite (see text fig. 6A). Apatite, epidote, and magnetite are accessories. Apatite, magnetite, titanite, hornblende, biotite, and the microcline "phenocrysts" are all euhedral.




Text Fig. 6.

Adamellite xenoliths in the porphyritic younger granite.

A. Granoblastic textured, showing association of titanite and magnetite (22517). Minerals are hornblende, biotite (B), plagioclase (slightly turbid), microcline (M), quartz (Q), titanite and magnetite.

B. Gneissic structured xenolith showing the development of titanite idioblasts (22581). Section from specimen taken from the edge of a xenolith near the contact between the granite and the xenolith.

Micrometric analysis of a more acid type of xenolith (22517) shows the following composition: Oligoclase 31 per cent., quartz 28 per cent., microcline 16.1 per cent., hornblende 11.1 per cent., biotite 8.3 per cent., epidote 2.7 per cent., titanite 1.6 per cent., magnetite 1 per cent., and apatite 0.2 per cent.

These xenoliths are best described as adamellites and are similar in many respects to the xenoliths in the granite at Victor Harbour, South Australia described by Kleeman (15a).

(b) *Uniform-grained granite.*

This differs from the porphyritic granite in being a uniform, medium-grained type with no xenoliths and no "phenocrysts," but very frequent aplite and pegmatite veins. The minerals are the same as in the porphyritic granite. Microcline forms clear irregular grains two to five mm. in size, which poikiloblastically enclose relics of quartz, oligoclase, and biotite. Microperthite is frequently developed. In one fresh looking specimen (22597) the microcline was extremely kaolinised. Oligoclase ($Ab_8$ $An_2$) occurs in extremely saussuritised grains (two to four mm.) considered to be relics from the granite gneiss and also in clear grains. Quartz and green chloritised biotite inclusions occur in the saussuritised form. The quartz occurs in two habits (i) small (0.1 to 0.3mm.) rounded inclusions in some of the microcline and oligoclase which may be relics from the granite gneiss, and (ii) larger, irregular, clear grains with an average size of three mm. Biotite is invariably associated with epidote and often with magnetite. It is a greenish-brown variety, X = light brown, Y and Z = dark green-brown to brown. This biotite may be developing from the epidote and magnetite. A pale green anhedral, moderately pleochroic amphibole with an extinction of about 20°, occurs closely associated with a micaceous mineral. The epidote, associated with biotite, is a strongly pleochroic type, optically negative with a large 2V. Pleochroism is from yellow (Z) to colourless (Y). Enhedral titanite, apatite, epidote, and magnetite are accessory minerals.

The approximate composition is microcline 35 per cent., oligoclase 30 per cent., quartz 25 per cent., biotite and amphibole eight per cent., titanite, epidote and apatite two per cent.

(c) *Granite from dyke* (22518).

This is a light grey, fine-grained, gneissic granite which occurs as a small dyke intrusive into the granitic gneiss.

The microstructure is allotriomorphic granitic with slight gneissosity due to flowage. The minerals are saussuritised oligoclase, grain-size 0.5 - 1.0 mm. ( 45 per cent.); clear microcline 0.5 mm. in diameter and rare phenocrysts up to 5 mm. in diameter (20 per cent.); quartz generally in very small rounded inclusions in the microcline and oligoclase poikiloblasts about 0.1 to 0.2 mm. in diameter and more rarely in larger irregular grains (20 per cent.); and greenish biotite associated with epidote (5 per cent). Apatite, zircon, and rutile are accessories.

(d) *Pegmatites and aplites.*

Pegmatite and aplite veins are frequent in the granites especially the uniform granite. Pegmatite, aplite, and quartz veins occur with less frequency in the granitic gneiss. Possibly some of these veins are genetically related to the Younger Granite. A small graphic granite outcrop occurs in the western band of metasediments in the southern part of the Area. This is a very coarse-grained, white graphic pegmatite (22575), composed of microcline (80 per cent.) up to two inches in grain-size and quartz (20 per cent.), frequently occurring at the edge of microcline crystals. Its genetic relationship is unknown.

A very coarse-grained magnetite-microcline pegmatite (22522) occurs in the granitic gneiss and is thought to have been derived from it in the end stages of crystallisation. Microcline (80 per cent.) grains are one to two inches in size and frequently have a graphic intergrowth of quartz within the grains. Irregular graphic quartz (8 per cent.), saussuritised plagioclase (6 per cent.) and magnetite (2 per cent.) make up the rest of the rock.

The coarse pegmatites, aplogranites, and aplites intrusive into the younger granites are all composed of quartz, saussuritised oligoclase, clear microcline (frequently microperthitic) and accessory epidote and green mica. The average composition is microcline 40 per cent., oligoclase 35 per cent., quartz 25 per cent.

No rare minerals have been found in any of the pegmatites.

*Origin of the Younger Granites.*—All the younger granites have the same mineral assemblage which is almost identical with the minerals of the granitic gneiss; there appear to be relic minerals (some oligoclase, hornblende, and quartz) of the granitic gneiss in the Younger Granite, and the rounded xenoliths in the porphyritic granite are very similar mineralogically to the xenoliths in the granitic gneiss, (the bluish green hornblende, one to two per cent. titanite and other minerals being common to both). So the Younger Granites appear to be the result of the palingenesis of the granitic gneiss and the xenoliths in the porphyritic granite are relics of the xenoliths in the granitic gneiss.

The "phenocrysts" of microcline with inclusions of all the other minerals were evidently of very late crystallisation. They occur as isolated crystals (fig. 5.) similar to the rapakivi ovoids which develop in the country rocks surrounding the rapakivi granite (25, p. 76) and they have evidently grown from potash emanations from the granite. Granitization, rather than crystallisation from a magma, is thought to have formed these poikiloblasts.

The reason for difference in texture between the porphyritic and the uniform-grained granite is not understood.

The granite dyke and many of the pegmatites are thought to be genetically related to the Younger Granites.

The retrograde metamorphism of sillimanite and cordierite of the metasediments to sericite and possibly the addition of silica in the formation of the cordierite-anthophyllite rock are thought to be the result of contact metamorphism by the Younger Granite.

## 2. Quartz Dolerites.

These are uniformly hard, dark grey, melanocratic rocks, holocrystalline, with fine to medium grain and a uniform texture.

Under the microscope an ophitic texture, uniform in character, is seen. The pyroxene is a pale purplish, non-pleochroic type, subhedral in form, in grains up to 1.5 mm. diameter partially changed to green uralite on the borders. It is optically positive with very weak dispersion, twinning, 2V approximately 40°, $\beta = 1.656$, extinction $c \wedge Z = 31°$—indicating pigeonitic diopside. The plagioclase is in euhedral laths (0.5 to 1.0 mm. long) showing albite twinning and more rarely pericline twinning. This plagioclase is perfectly fresh labradorite ($Ab_{45}$ $An_{55}$) with normal gradational zoning sometimes developed. Ilmenite occurs in irregular opaque areas up to one mm. in diameter. It appears to have crystallised in the interstices between the earlier formed plagioclase and pyroxene grains. There is a peripheral reaction rim round the ilmenite of a brownish chloritic material and chlorite stringers pass out into the plagioclase. Quartz and apatite are accessory minerals. Approximate mineralogical composition is labradorite 50 per cent., pyroxene 40 per cent, ilmenite nine per cent., quartz one per cent. The rock is slightly uralitised quartz dolerite.

The borders of the dykes are made up of fine-grained uralitised dolerite showing more advanced uralitisation than the central parts. In these finer-grained rocks the pyroxene is seen to be extensively uralitised to a greenish amphibole which is moderately pleochroic, X = light purplish colour, Y = green, Z = bluish green and the extinction is approximately 16°. Anhedral plates of strongly pleochroic biotite are seen with X = light brown, Y and Z = very dark brownish green. The ilmenite is partially leucoxenised. There are occasional veinlets of epidote.

Order of crystallisation:—pyroxene and labradorite, then ilmenite, and lastly quartz (primary minerals), and, resulting from end phase hydrothermal action and subsequent movement between dyke and country, biotite, epidote, leucoxene, and actinolite. All the dykes are more uralitised at the edges because of subsequent movement between dyke and country rock. Prider (22, pp. 46-48) has studied this phenomenon in more detail at Armadale. The approximate composition is labradorite 48 per cent., pyroxene 25 per cent., actinolite 15 per cent., ilmenite seven per cent., quartz two per cent., biotite and epidote three per cent.

*Origin of the quartz dolerites.*—These hypabyssal, slightly uralitised quartz dolerites are thought to be part of a very widespread dyke intrusion throughout the State in Late Pre-Cambrian or Lower Cambrian time (24). The dykes were intruded along lines of weakness caused by mild diastrophism.

A narrow zone showing slight contact metamorphism—largely epidotisation of the country rocks—surrounds the dykes.

## V. ECONOMIC GEOLOGY.

Refractory minerals and banded iron ore, in the south-west of the area are the only minerals of economic importance in the area.

### A. REFRACTORIES.

(i) *Sillimanite.*

Refractory clays derived from the kaolinisation of sillimanite mica schists of the Jimperding Series have been quarried for the manufacture of firebricks at Clackline for some years (26, p. 11; 16, p. 13). The sillimanite content of the clay is estimated to vary from five to 10 per cent. of the rock (26, p. 12).

(ii) *Sand.*

A pure white quartz sand derived from the quartzites in the west of the area is being utilised by the Clackline Firebrick Company.

### B. CHARCOAL IRON.

Banded iron ore deposits occur two miles west-north-west from Clackline Railway Station. These have been mapped and described by Hobson (G.S.W.A. File 237/1910) who states that up to the end of 1907 they had produced 18,253 tons of iron ore for use as a flux. These deposits are the result of lateritisation of iron-rich metajaspilites of the Jimperding Series. The area of iron-rich rocks is approximately 60 square chains according to Hobson's map; and the average iron content is 45.5 per cent. A plant is being erected at Wundowie, about 10 miles to the west-south-west of Clackline, to obtain pig iron from similar ore, using charcoal as a fuel for smelting.

[Hobson's Map and Report "Proposed drilling in the vicinity of the Clackline ironstone deposits" has since been published in the W.A. Mines Dept. Ann. Rept. for 1945, pp. 58-60.—Ed.]

## VI. HISTORY OF THE AREA.

1. In early Pre-Cambrian time argillaceous, arenaceous and iron-rich sediments (jaspilites) were deposited along with contemporaneous tuffs and basic igneous lava flows or sills.

2. An orogenic period accompanied by the intrusion of a granitic magma followed.

At this stage the sediments suffered regional metamorphism under sillimanite zone conditions and considerable plastic flowage took place in the less competent argillaceous facies. There was no further orogeny or regional metamorphism after this period.

3. The granitic magma did not completely crystallize until after the folding had ceased (23, p. 109). It consolidated as granitic gneiss sills of huge size which indicates that the folding had taken place at considerable depth (4, p. 294, 2, p. 81).

4. A relatively short time, geologically speaking, after the complete consolidation of the granitic gneiss, palingenesis of the granitic gneiss and sediments of the Jimperding Series took place. At the end of the orogenic period the base of the orogene would be at a great depth and under great pressure due to the superincumbent load of sediment. A lag in isostatic adjustments appears to occur after orogeny in which the surface projections of the orogene are eroded. The erosion of the surface part of the orogene would reduce the pressure on the acid rocks at depth so that palingenesis may have followed (18, pp. 330-332).

This palingenic granite magma (the Younger Granite) was now intruded into the Jimperding Series. Some contact metamorphism was effected by this intrusion, probably the most important change being the retrograde metamorphism of the earlier formed high-grade sillimanite and cordierite to sericite.

5. In Late Pre-Cambrian (Nullagine) or Lower Cambrian time (24), after considerable erosion had taken place, quartz dolerite dykes were intruded along lines of weakness possibly caused by mild diastrophism.

The cataclasis noted in some of the granitic gneisses and quartz veins and the epidotisation of country along veins emanating from the dykes may have occurred at this stage.

6. A long period of erosion followed, culminating in a peneplain on which residual laterite deposits were formed in Miocene (29, p. 17, 32, p. 125) or Pliocene times. There was probably a moderate to high rainfall at the time of formation of the laterite (20, p. 47, 29, p. 19).

7. A new cycle of erosion was initiated by the epeirogenic uplift of the ancient peneplain to form the Great Plateau of Western Australia in Pliocene and Pleistocene times (8, p. 288). The area is now a dissected plateau with laterite-capped mesas and buttes representing residuals of the old peneplain, above which project ridges of more resistant quartzites.

## VII. ACKNOWLEDGMENT.

I wish to express my deepest thanks to Professor E. de C. Clarke for his many helpful suggestions and discussions during the preparation and revision of this paper.

I also wish to thank Dr. R. T. Prider for his very great help in the field, in the practical work, and for his advice in the preparation of the text.

The mapping of the area described was done in the course of field instruction classes, by parties of senior geology students of the University of Western Australia in 1939 and 1945. Many of the thin sections used in the preparation of this paper were cut by these students. The author desires to express his gratefulness for this assistance.

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